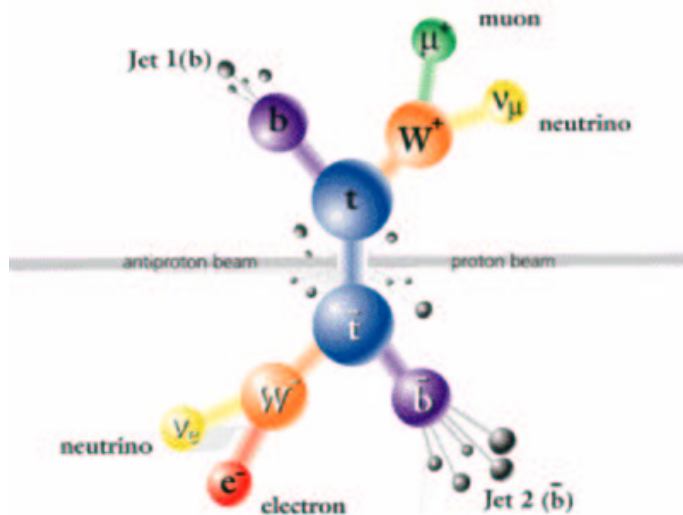




TOP PHYSICS AT CDF



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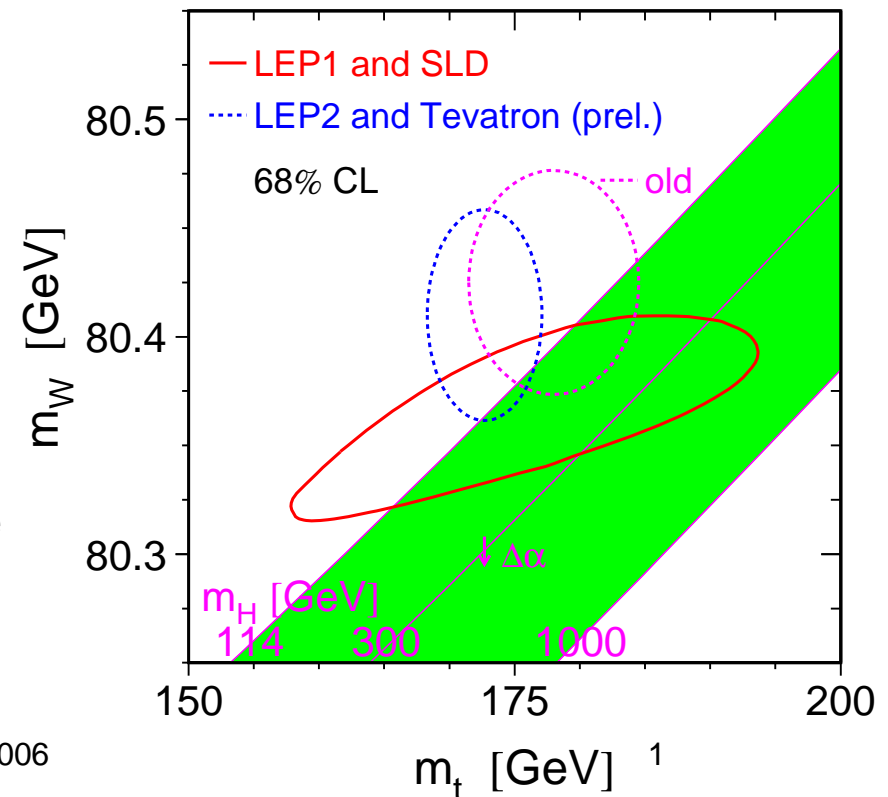
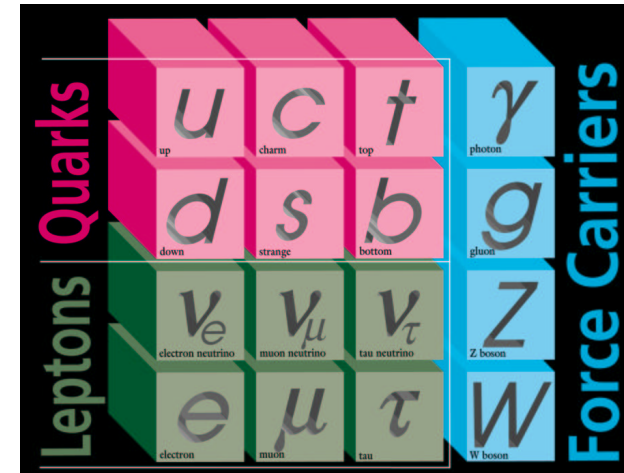
for the CDF Collaboration



Lake Louise Winter Institute, February 17-23, 2006

Why is Top Quark so interesting?

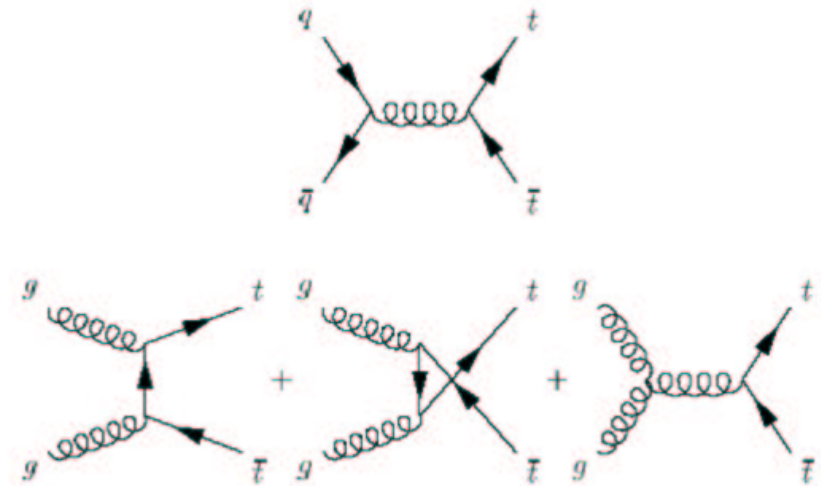
- **Heaviest** known fundamental particle \Rightarrow high p_T physics
- **Decays before it can hadronize** ($\tau_{top} \sim 10^{-24}$ sec) \Rightarrow momentum and spin pass to the decay products
- Look for new physics
- Top quark properties **test SM**
 - ◇ Higher x-sec than predicted could be a sign of non SM production mechanisms
- Top mass **fundamental parameter** in SM
 - ◇ M_t , along with the mass of the W, is related with the mass of the Higgs boson



Top Production & Decay Modes

- At Tevatron energies ($\sqrt{s} = 1.96 \text{ TeV}$) tops are mainly produced in **pairs via strong interaction**

- ◇ $q\bar{q}$ annihilation (85%) or gluon fusion (15%)
- ◇ $\sigma(p\bar{p} \rightarrow t\bar{t} @ M_t = 175 \text{ GeV}) \approx 6.7 \text{ pb} \Rightarrow$ **one top event every 10 billion inelastic collisions**

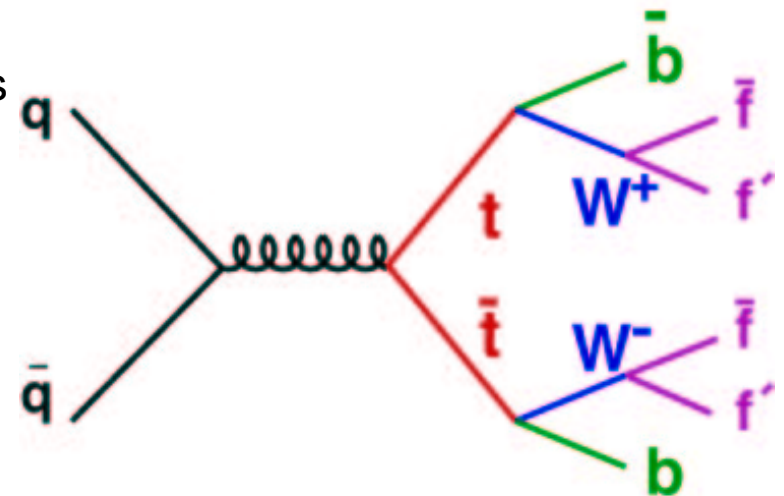


- Decays via electroweak interaction $t \rightarrow Wb$

- ◇ $\text{BR}(t \rightarrow Wb) \approx 1 \Rightarrow$ final state given by the W^\pm decays
- ◇ $\text{BR}(W \rightarrow \text{leptons}) = 1/3, \text{BR}(W \rightarrow \text{quarks}) = 2/3$

lepton \equiv electron or muon

Final State	Dataset	BR
$l\nu l\nu b\bar{b}$	dilepton	$\sim 5\%$
$l\nu qq b\bar{b}$	lepton+jets	$\sim 30\%$
$qq qq b\bar{b}$	hadronic	$\sim 44\%$



Detecting the Top Quark

- Top events:

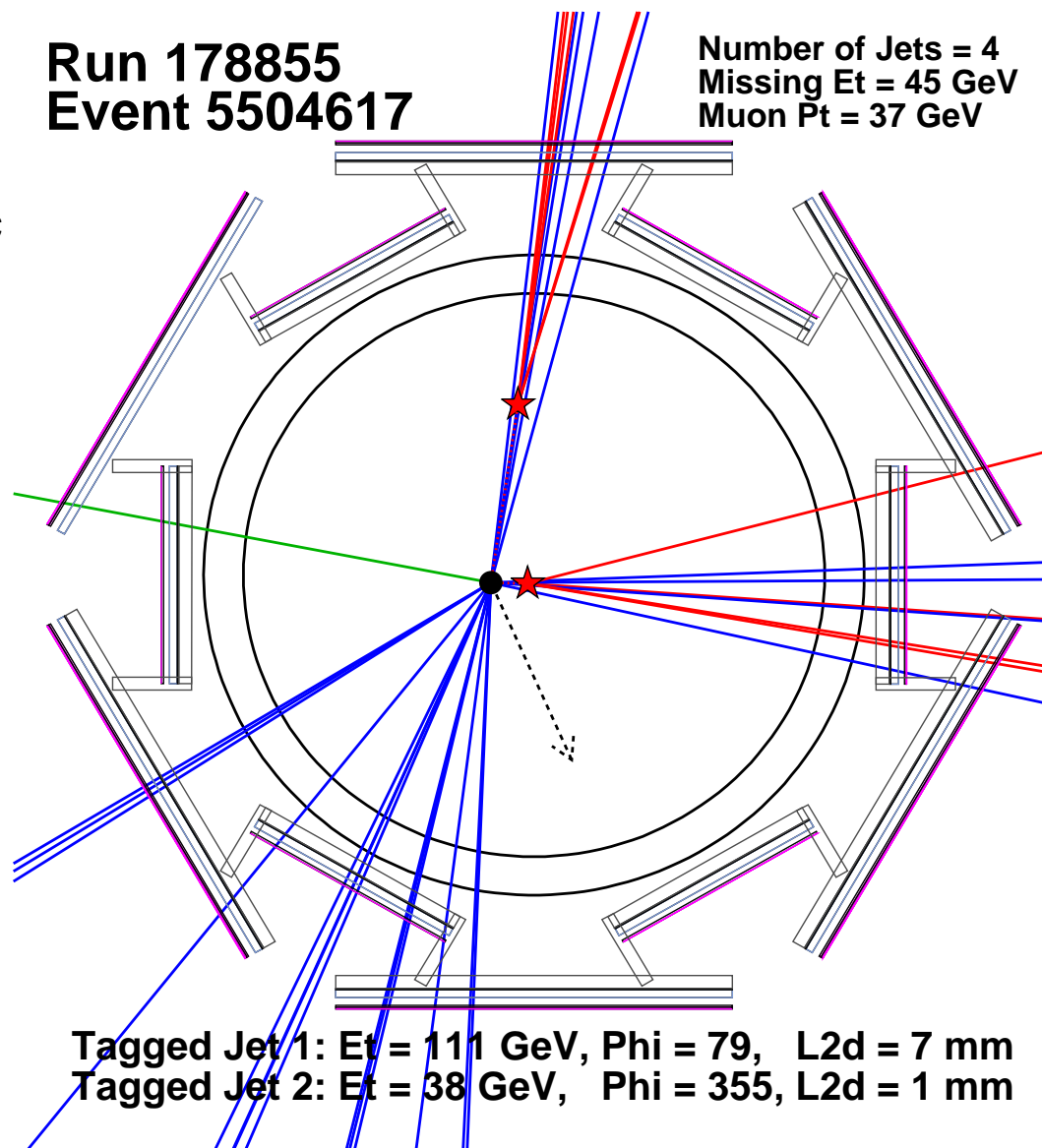
- ◇ are energetic, central and spherical
- ◇ have \cancel{E}_T from neutrinos in leptonic modes
- ◇ have jets with high E_T
- ◇ have **two high E_T b-jets**

- Main backgrounds:

- ◇ Dilepton: $Z \rightarrow l^- l^+$
- ◇ L+jets: $W + jets$ (few % have b or c)

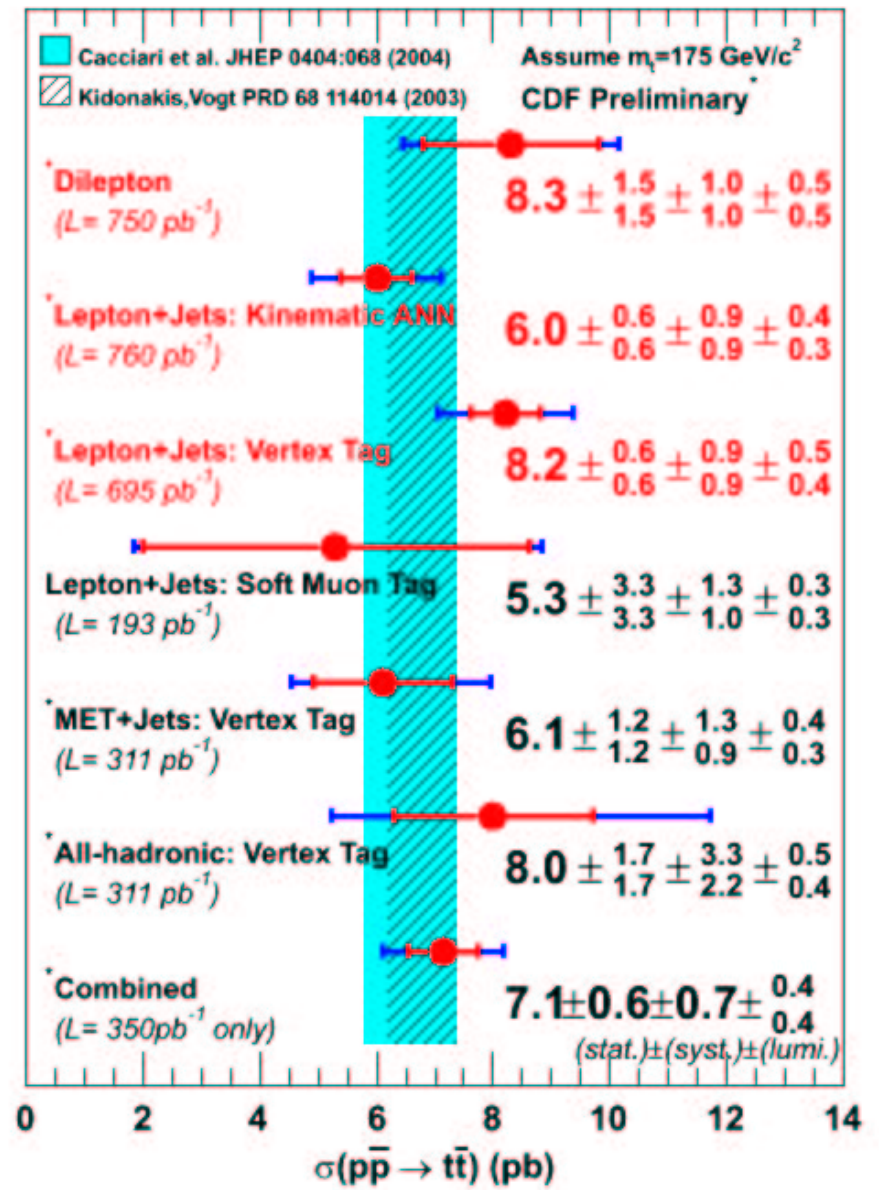
- b-tagging improves S/B (SecVtx, Jet Probability, Soft Lepton Tagger)

- ◇ Top event tag efficiency $\sim 55 - 60\%$
- ◇ Mistag rate $\sim 1\%$



Production Cross Section Measurements

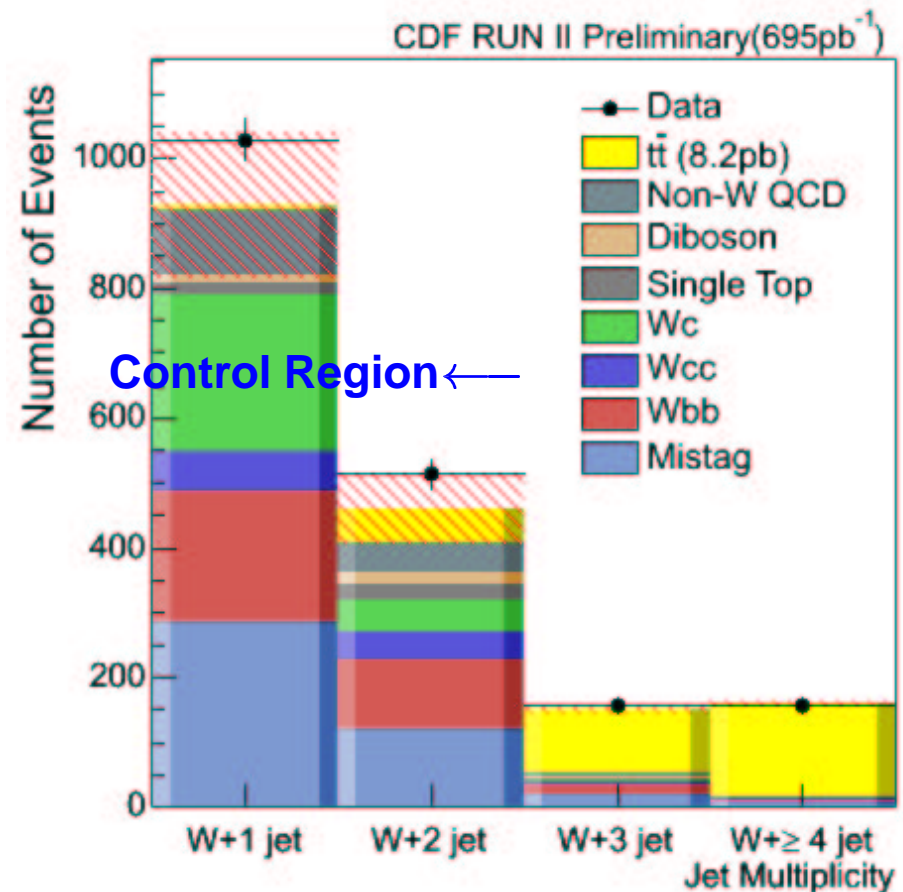
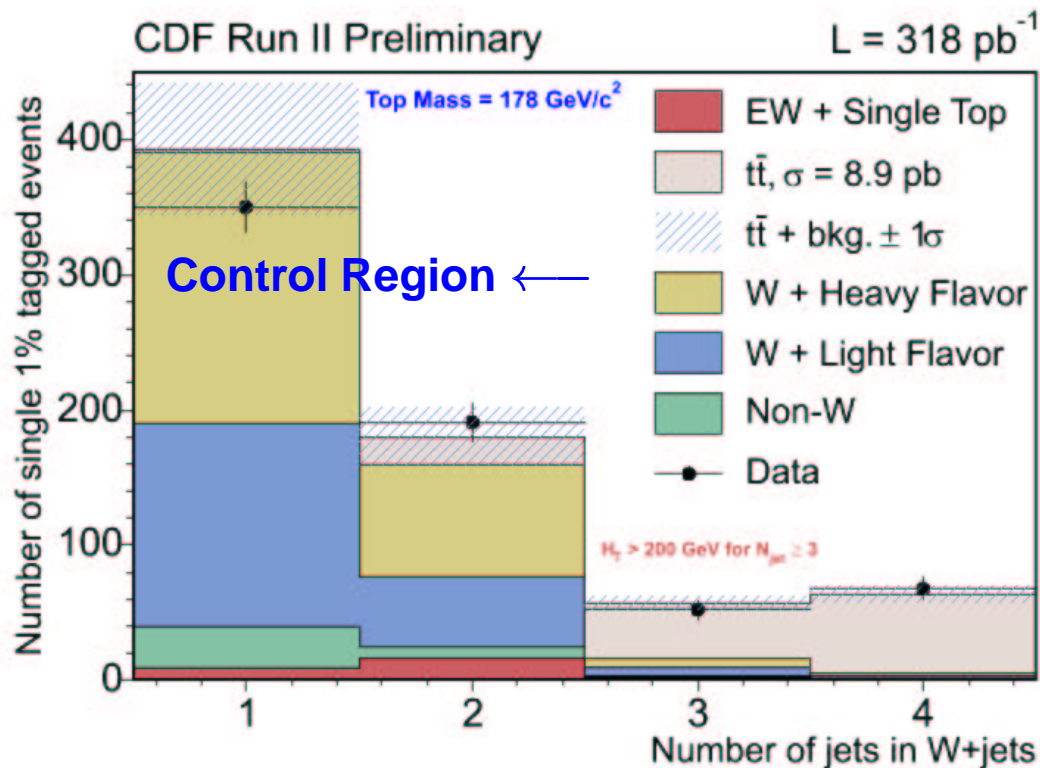
- Counting experiment: $\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{A \times \epsilon \times \int L dt}$
- Test non-SM top production mechanism
- Look for new physics in the top samples
- Goal: demonstrate good understanding of backgrounds in control region and observe excess from top in signal region
- Measurements in different final states are consistent with each other and with theory
- Most of the results I will show here are **new**



$\sigma_{t\bar{t}}$ in Lepton+Jets with b-tagging

- Selection: 1 isolated lepton (e, μ) with $p_T > 20$ GeV, $E_T > 20$ GeV, ≥ 3 jets with $E_T > 15$ GeV, ≥ 1 b-tagged jet
- Main backgrounds: $Wb\bar{b} / Wc\bar{c} + \text{jets}$, QCD, mistags **SecVtx** ($L = 695 \text{ pb}^{-1}$)

Jet Probability ($L = 318 \text{ pb}^{-1}$)

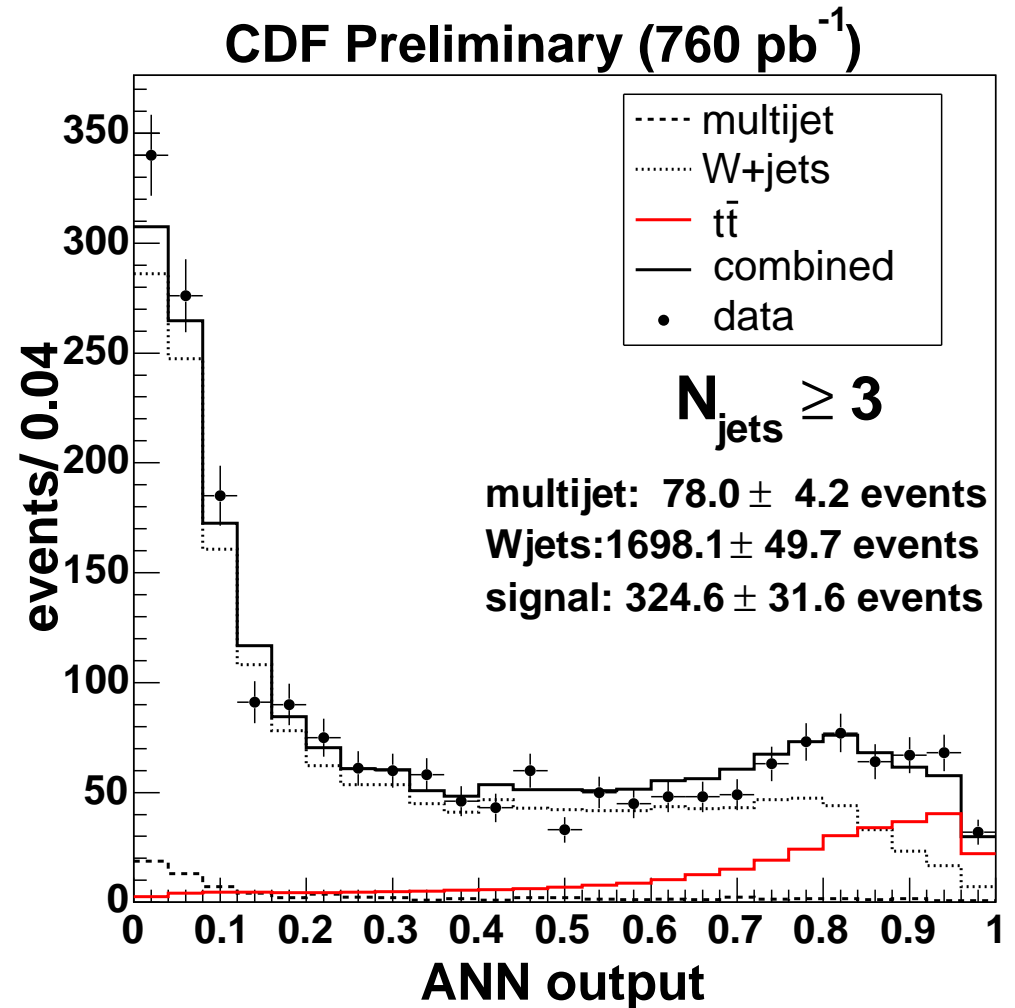


$$\sigma_{t\bar{t}} = 9.1 \pm 1.1 \text{ (stat)} \pm 1.0 \text{ (syst)} \text{ pb}$$

$$\sigma_{t\bar{t}} = 8.2 \pm 0.6 \text{ (stat)} \pm 1.0 \text{ (syst)} \text{ pb}$$

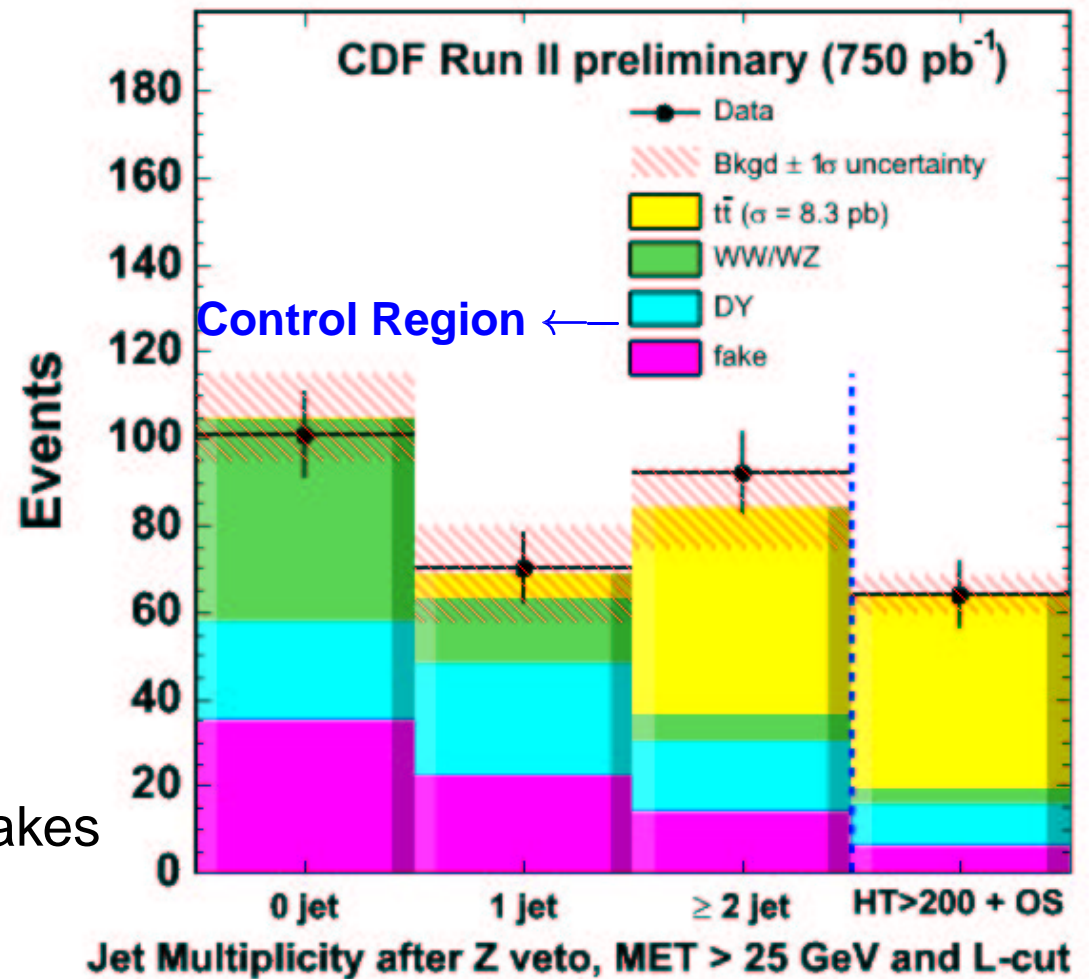
$\sigma_{t\bar{t}}$ in L+Jets without b-tagging ($L = 760 \text{ pb}^{-1}$)

- Same selection criteria but **no b-tagging** is required \Rightarrow higher statistics but larger backgrounds also
- Different backgrounds systematics than in tag analysis
- Kinematical analysis using a **Neural Network**
- 325 $t\bar{t}$ events!!!!
- $\sigma_{t\bar{t}} = 6.0 \pm 0.6 \text{ (stat)} \pm 0.9 \text{ (syst)} \text{ pb}$



$\sigma_{t\bar{t}}$ in Dilepton ($L = 750 \text{ pb}^{-1}$)

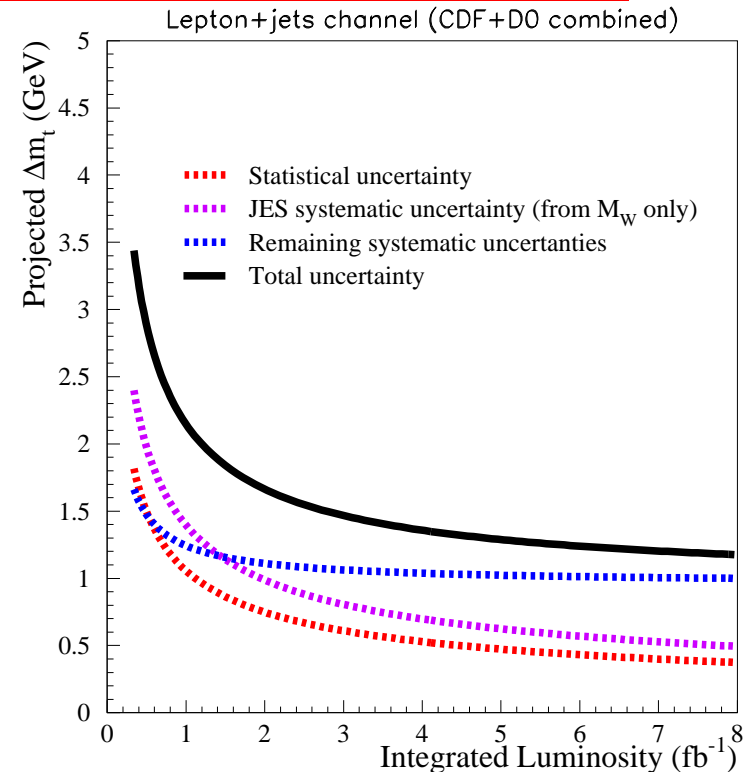
- Both W's decay to lepton and neutrino
- Very **clean** sample.. but **low** statistics
- Selection: 2 isolated lepton (e, μ) with $p_T > 20 \text{ GeV}$, ≥ 2 jets with $E_T > 15 \text{ GeV}$, $E_T > 25 \text{ GeV}$
- Main backgrounds: DY, dibosons, fakes



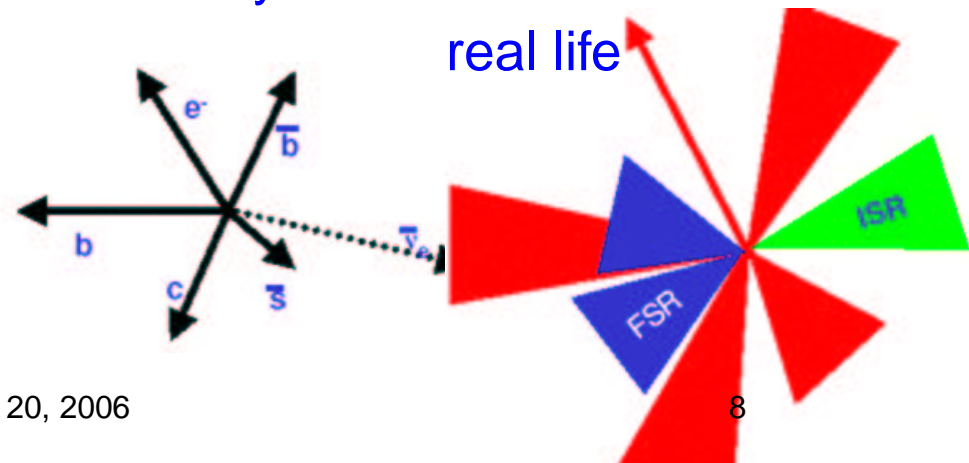
$$\sigma_{t\bar{t}} = 8.3 \pm 1.5 \text{ (stat)} \pm 1.0 \text{ (syst)} \pm 0.5 \text{ (lum)} \text{ pb}$$

Top Quark Mass

- Fundamental parameter of the SM
- Many different methods applied at CDF: trying to optimize the stat. and syst. performance
- Design goal: $\delta M_t \sim 2\text{-}3 \text{ GeV}$
- Largest uncertainty: Jet Energy Scale measurement
- Very challenging measurement!
 - ◇ Undetected neutrino(s)
 - ◇ Many different ways to assign jets to partons
 - ◇ Small statistics
 - ◇ Large energy resolution for jets

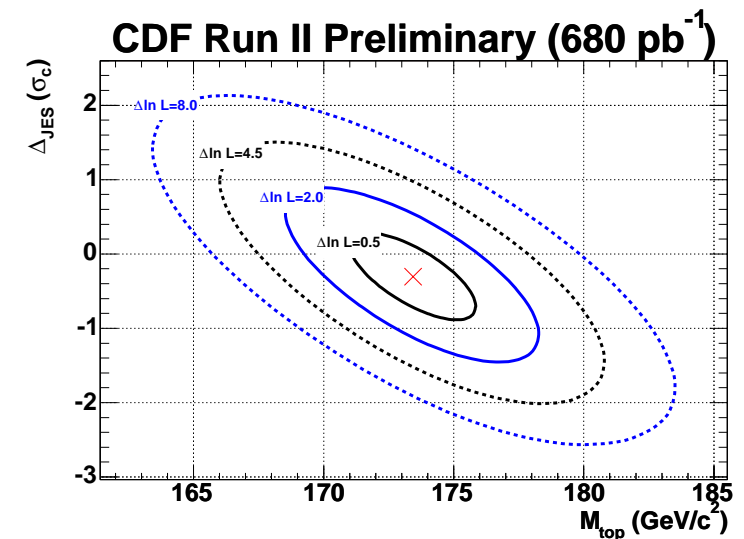
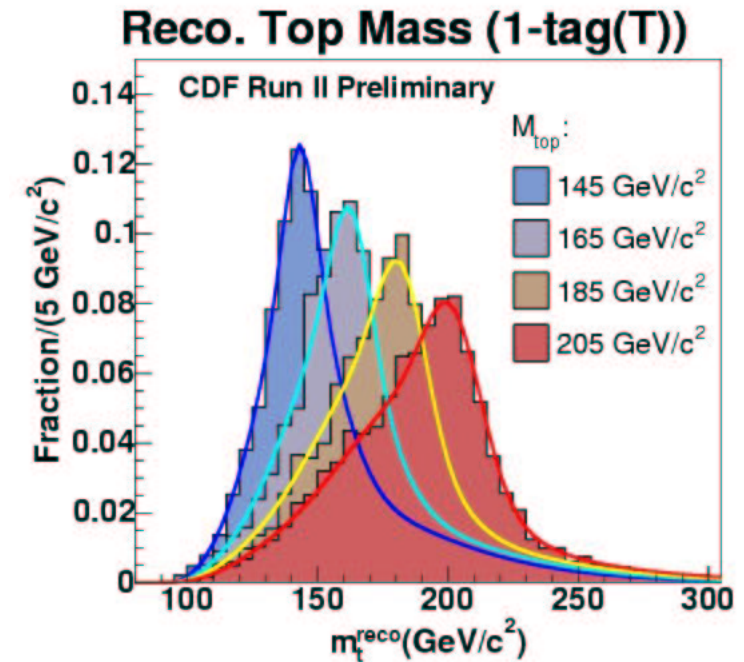


theory



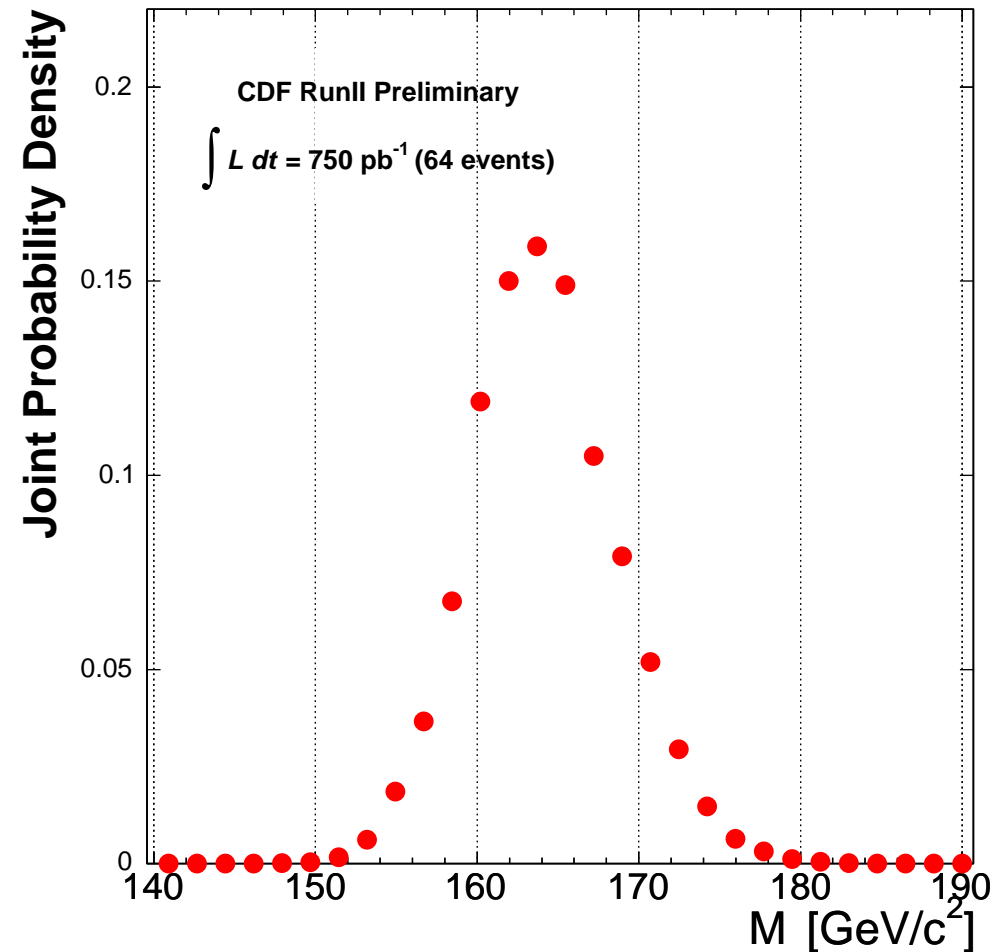
M_t with Templates in L+Jets ($L = 680 \text{ pb}^{-1}$)

- Reconstruct event-by-event M_t
- Create templates using events simulated with different M_t values
- Simultaneous fit to top mass and JES using $W \rightarrow jj$ decays
- $M_t = 173.4 \pm 2.5 \text{ (stat + JES)} \pm 1.3 \text{ (syst)} \text{ GeV}$
- $\Delta_{JES} = -0.30^{+0.59}_{-0.58} \sigma_c$



M_t with ME in Dilepton ($L = 750 \text{ pb}^{-1}$)

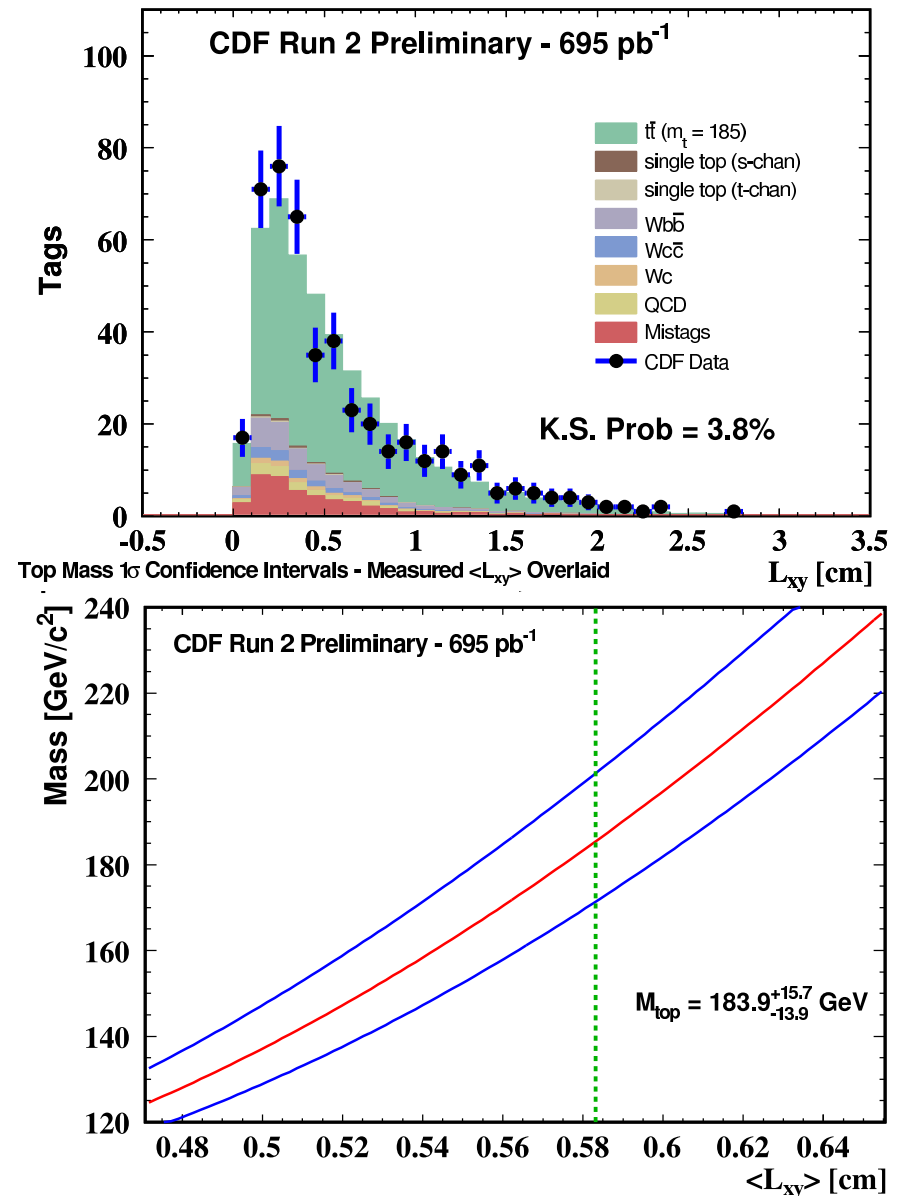
- 2 neutrinos, small branching ratio...
- ... but fewer combinatorics
- Matrix element technique
- Use all available information about the event in the fit
- $M_t = 164.5 \pm 4.5 \text{ (stat)} \pm 3.1 \text{ (syst)} \text{ GeV}$



Top Mass: a different approach... in L+Jets ($L = 695 \text{ pb}^{-1}$)

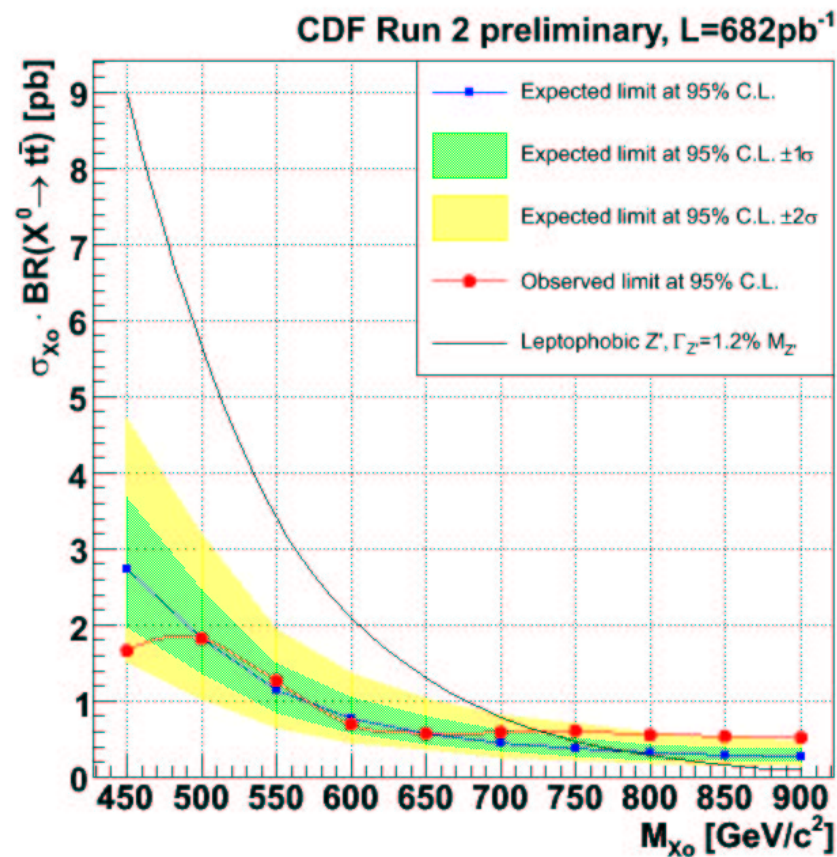
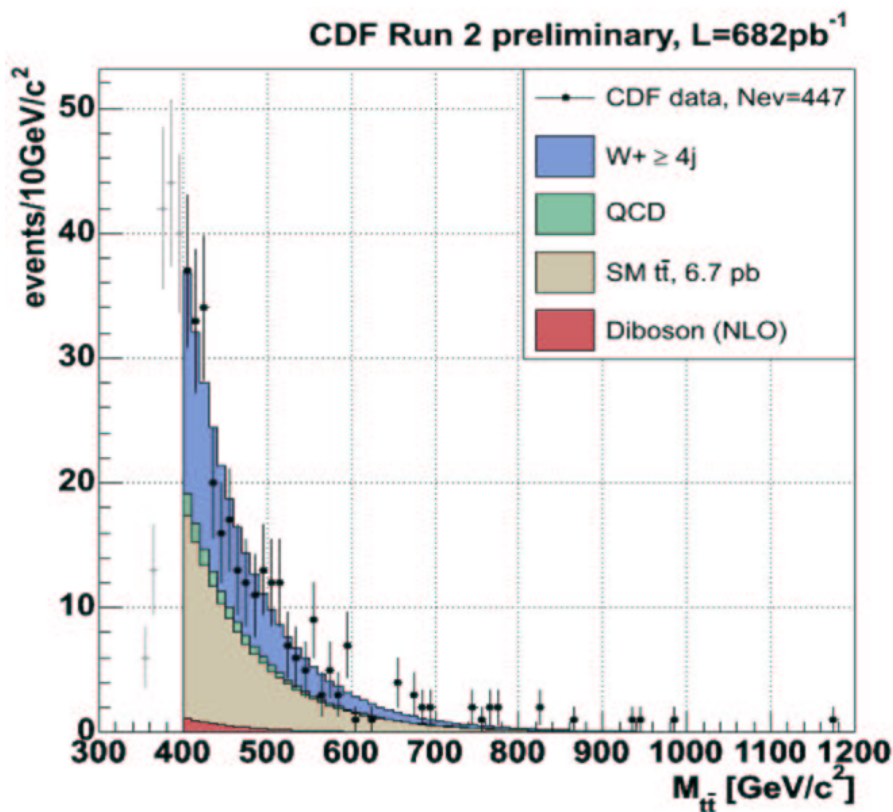
- No more full event reconstruction!
- Relies on tracking information (decay length of b's, L_{xy})
- $\langle L_{xy} \rangle = 0.5808 \pm 0.0227 \text{ cm}$
- $M_t = 183.9_{-13.9}^{+15.7} (\text{stat}) \pm 5.6 (\text{syst}) \text{ GeV}$
- Statistically limited @ Tevatron
- ... but does not depends on JES

Transverse Decay Length - Tagged W + ≥ 3 Jet Events

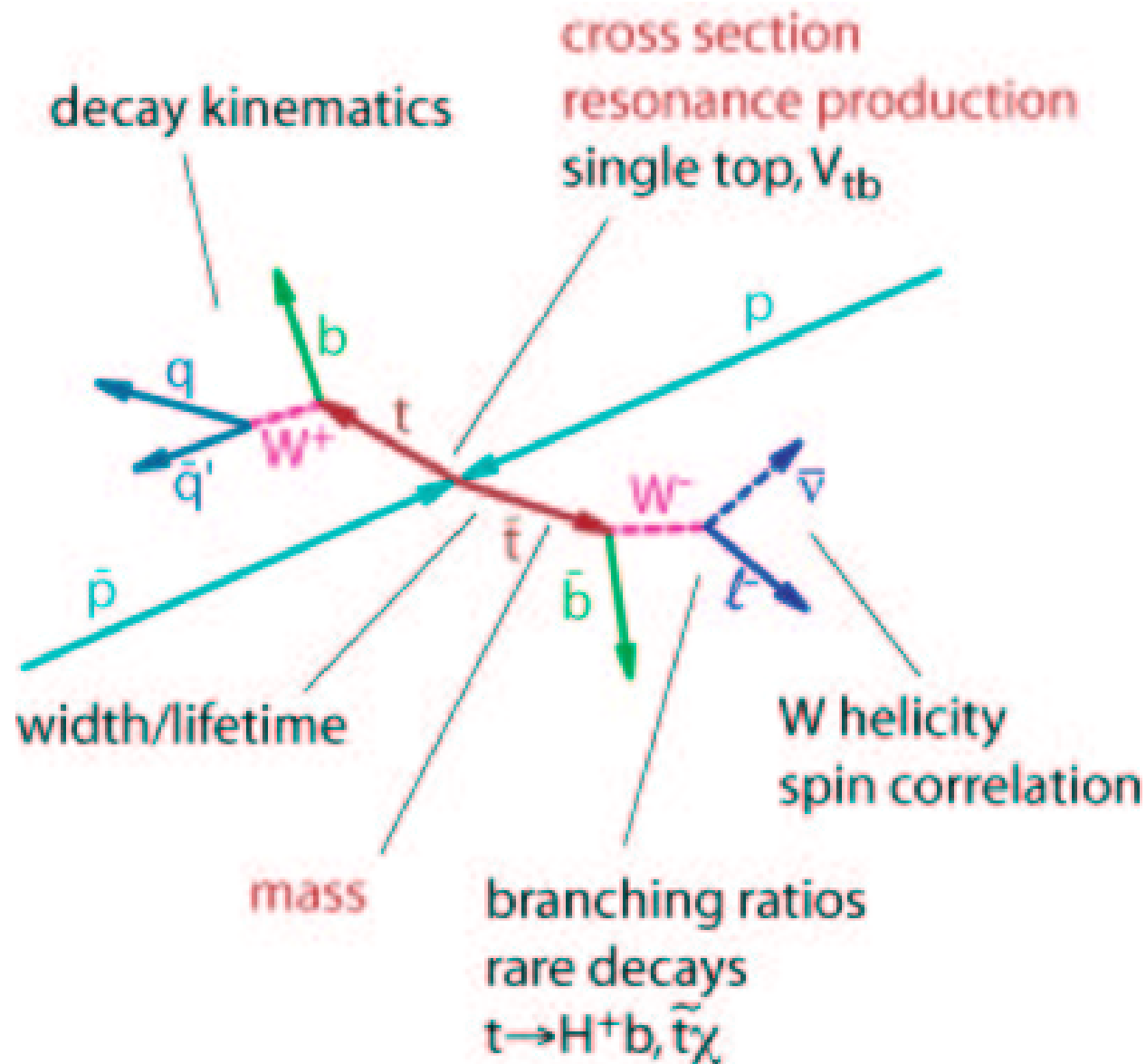


Searches for $t\bar{t}$ resonances: $p\bar{p} \rightarrow X^0 \rightarrow t\bar{t}$ ($L = 682 \text{ pb}^{-1}$)

- Search for new massive resonance decaying to top pairs (predicted by some exotic models)
- $t\bar{t}$ invariant mass spectrum ($M_{t\bar{t}}$) for top candidates in the $l+jets$ sample
- Test the consistency of the data with SM $t\bar{t}$ production



TOP PHYSICS IS HUGE!!!



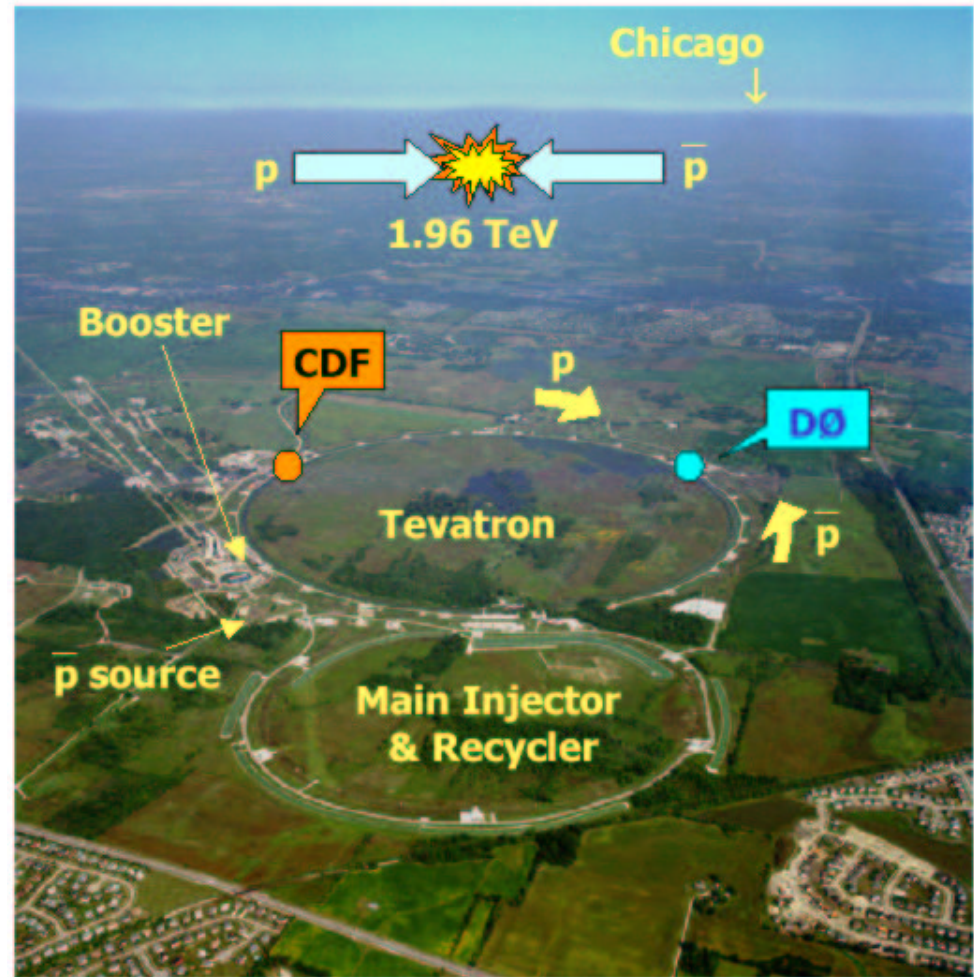
Conclusions

- Experimental top quark physics at CDF is in a **mature state**
 - ◇ A **lot of people** involved \Rightarrow great variety of analyses
 - ◇ No evidence of non-SM top quark... so far
 - ◇ But still many chances of discovery at CDF
- Shown results with $\sim 700 \text{ pb}^{-1}$, data taken in Sept 05 have already been analysed
- Many top physics results at CDF have been **published** (18). And (even) **more precise** measurements are coming soon
 - ◇ Expect to have many more results with $\sim 1 \text{ fb}^{-1}$ of data for summer conferences
- Extremely rich top physics program at Tevatron

BACK-UP SLIDES

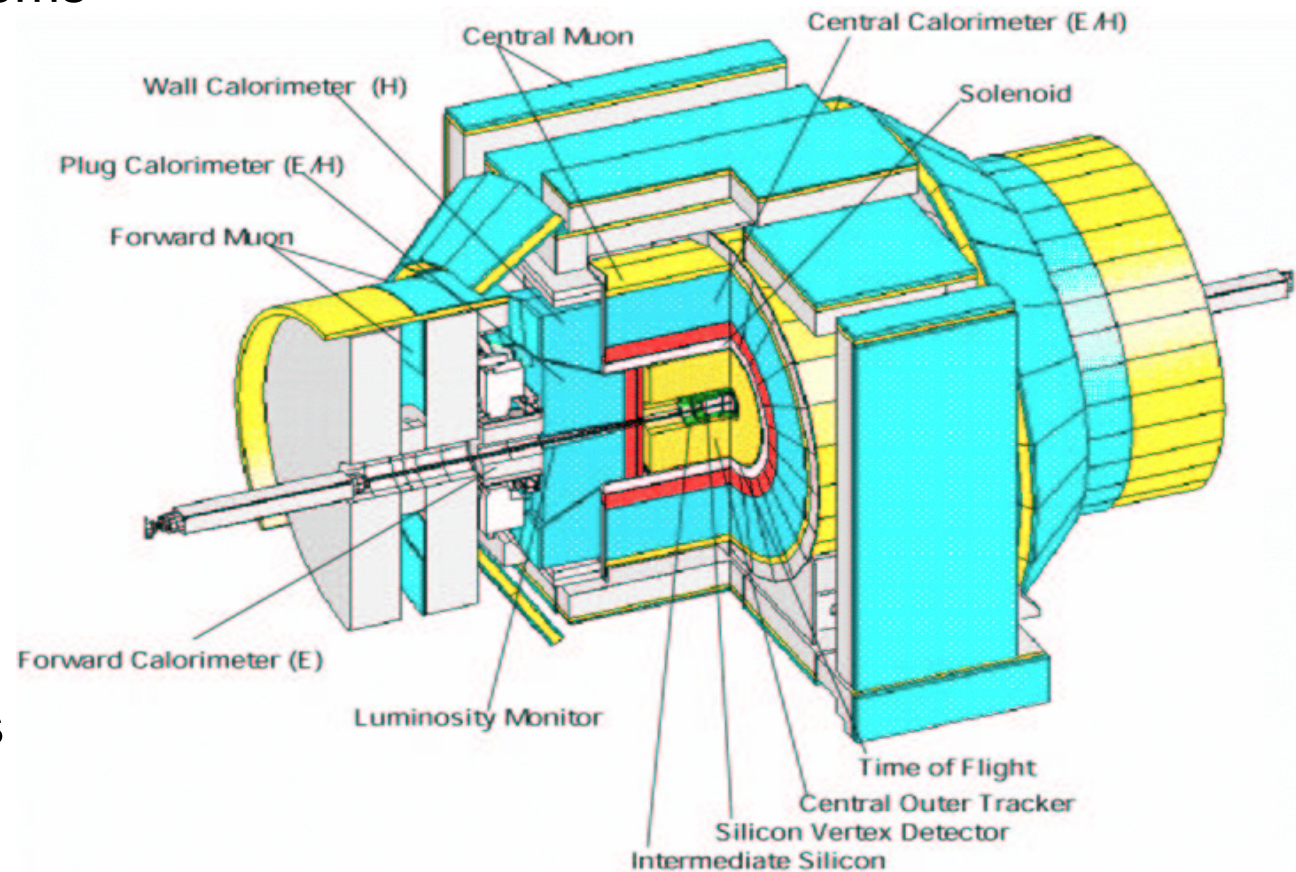
The Tevatron

- Currently, the world's only top quark production machine
- Highest energy $p\bar{p}$ collider
 - Energy of the beam = 980 GeV
 - $\sqrt{s} = 1.96\text{ TeV}$ (Run I $\rightarrow 1.8\text{ TeV}$)
- Collisions every 396 ns (Run I $3.5\text{ }\mu\text{s}$)
- Run I: 1992 - 1996 (quark *top*!)
- Run II: 2001 - nowadays
 - Many improvements: *Main Injector*
 - \mathcal{L}_{int} : 100 pb^{-1} (Run I) $\rightarrow > 1\text{ fb}^{-1}$ (Run II)
- Other discoveries: quark *bottom* (1977) y ν_τ (2000)

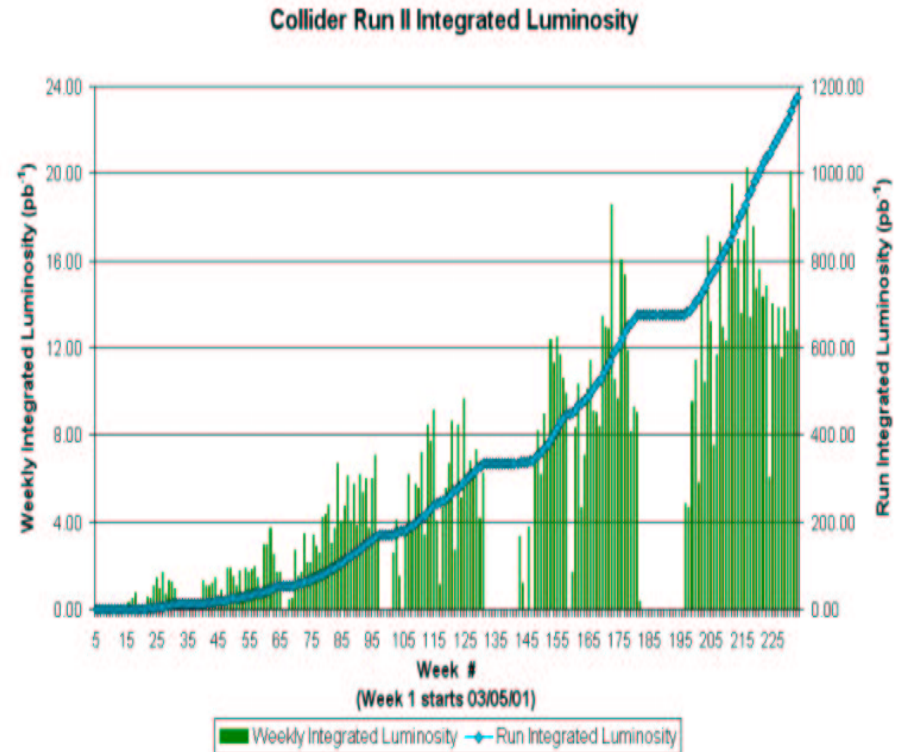
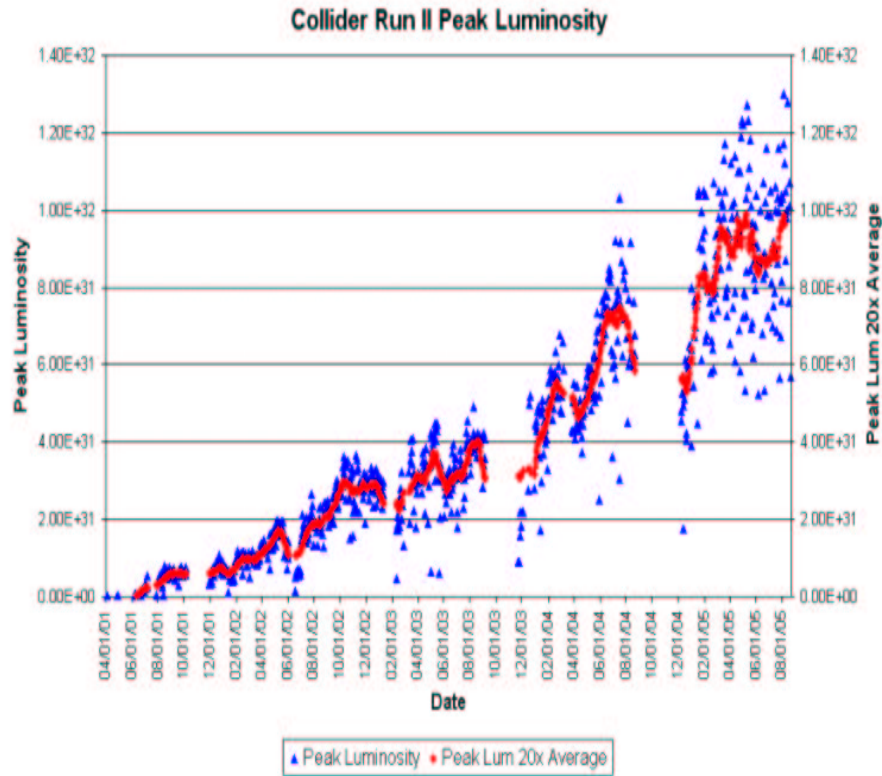


CDF

- General-purpose particle detector. Cylindrical symmetry
- 3 subsystems: tracking (inside a 1.4 T solenoidal magnetic field), calorimetry and muons systems
- For top physics, the full detector is needed
- Run II improvements:
 - New Silicon detector
 - TOF detector
 - *plug* calorimeters
 - *forward* μ detectors
 - DAQ & triggers electronics
 - L2 SVT trigger



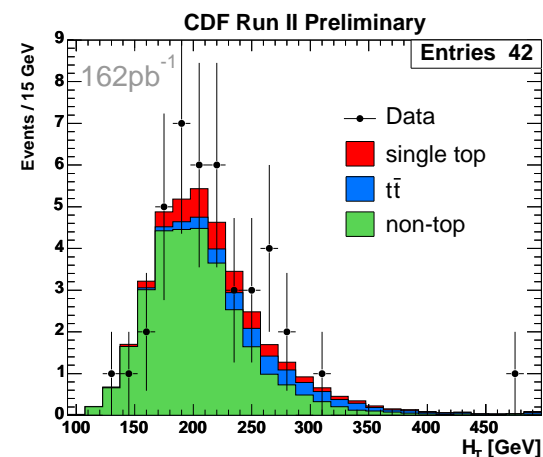
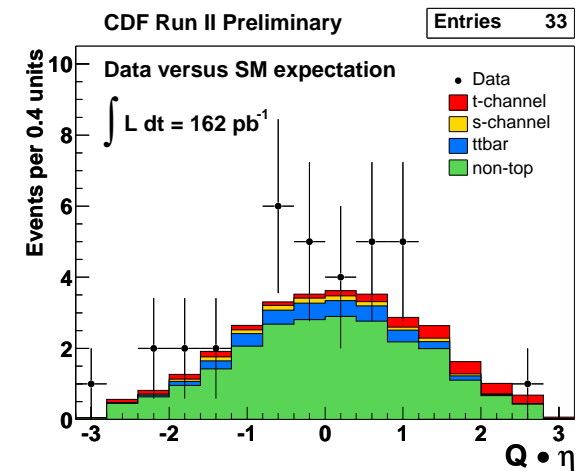
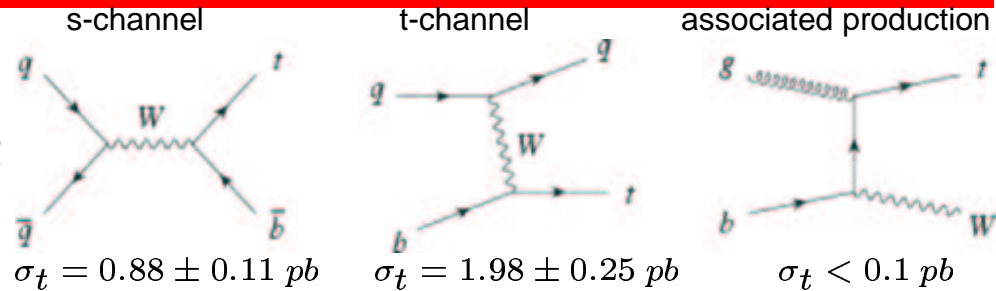
Tevatron: Luminosity (Run II)



- $\mathcal{L}_{inst}^{max} \sim 1.8 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, $\mathcal{L}_{int} \sim 1.5 \text{ fb}^{-1}$ ($\sim 1.2 \text{ fb}^{-1}$ on tape)
- $\mathcal{L}_{int} \sim 4.4$ (main goal)- 8.5 (design) fb^{-1} in 2009?

Single Top Quark Production

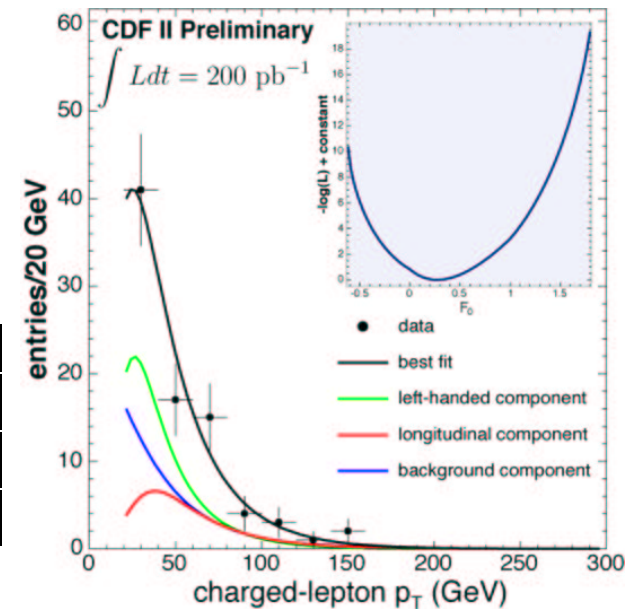
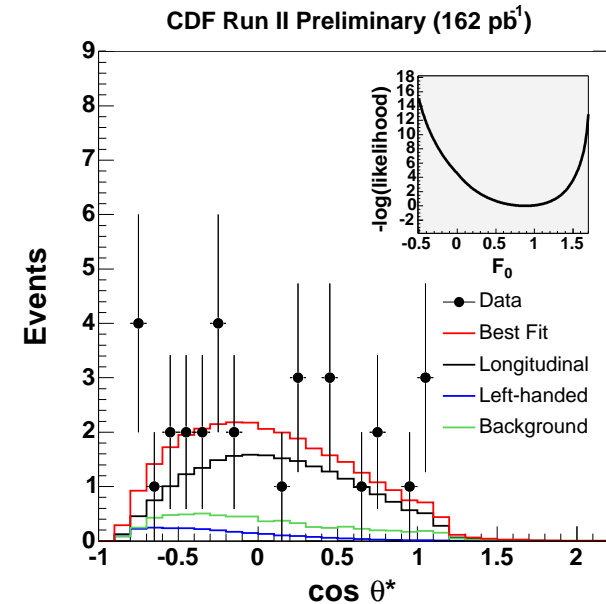
- It is possible via EW processes
 - Cross section \propto matrix element $|V_{tb}|^2$ (direct measurement)
 - Production channel sensitive to new physics
- Not yet observed at CDF. Set upper limits
- Final state: lepton, \cancel{E}_T , 2 jets (at least 1 b-jet)
- Two different analysis ($L = 162 \text{ pb}^{-1}$)
 - Separate search channels (reveal new physics, $Q \times \eta$ distribution)
 - Combined search (H_T distribution)



Measurement	σ_t @ 95% CL (pb)	$\int L dt$
s-channel	< 13.6	162
t-channel	< 10.1	162
combined	< 17.8	162

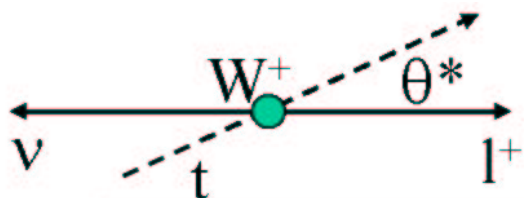
W Helicity from Top Decay

- W boson has three helicity states
 - Left handed, longitudinal, right handed
 - Top quark decays mostly to longitudinal W's
- Measuring the fraction of longitudinal W's (F_0):
 - we test a SM prediction: $F_0 = 0.7$ ($F_- = 0.3$, $F_+ = 0$)
 - we test the nature of the tWb vertex
- Kinematic distributions for each helicity state are very different



Method	Sample	$\int L dt \text{ (pb}^{-1}\text{)}$	F_0	Limit@95% CL
$\cos \theta^*$	l+jets	162	$0.99^{+0.29}_{-0.35} \pm 0.19$	> 0.18
lepton p_T	combined	200	$0.31^{+0.37}_{-0.23} \pm 0.17$	< 0.95
Combined	-	-	$0.74^{+0.22}_{-0.34}$	-

W Helicity from Top Decay



left-handed

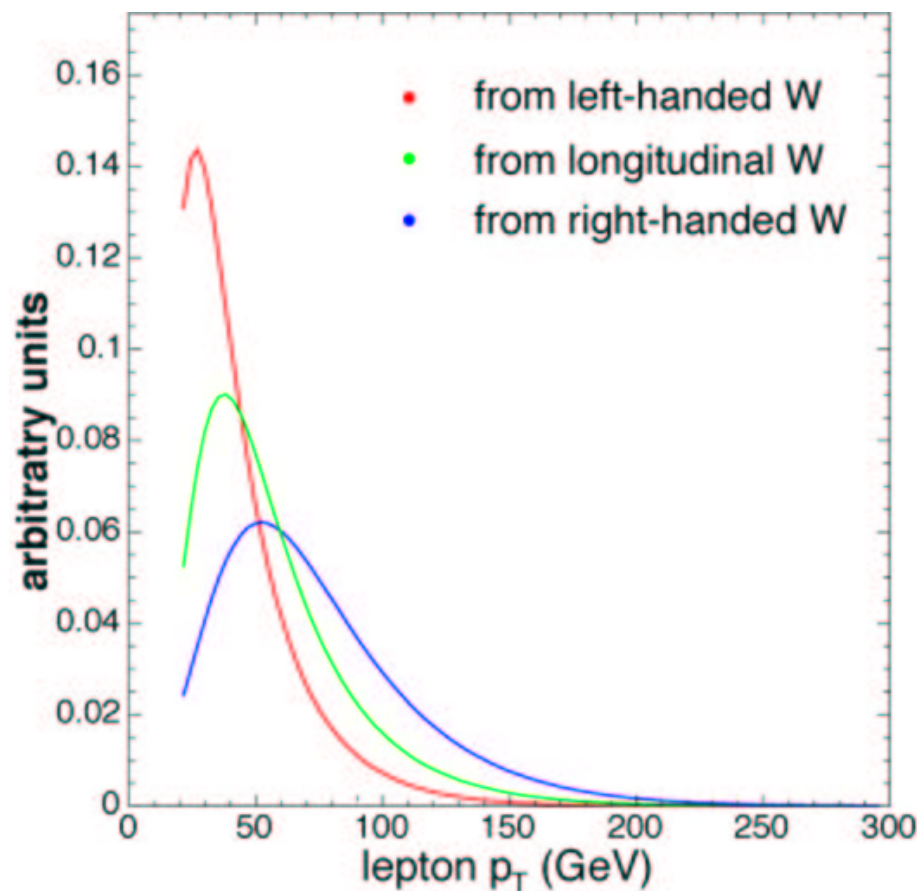
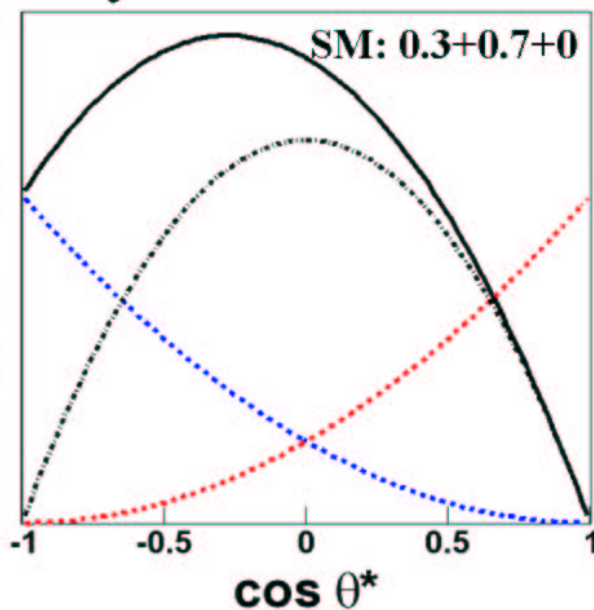
$$\frac{1}{4}(1 - \cos \theta^*)^2$$

longitudinal

$$\frac{1}{2}(1 - \cos^2 \theta^*)$$

right-handed

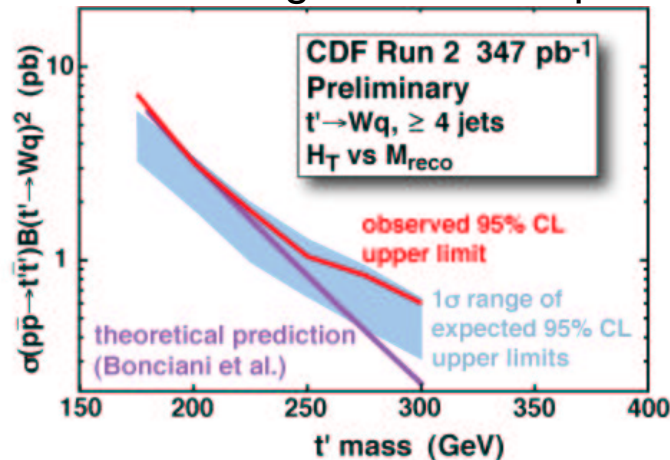
$$\frac{1}{4}(1 + \cos \theta^*)^2$$



Other Top Properties Measurements

Measurement	Result	$\int L dt \text{ (pb}^{-1}\text{)}$
W helicity F_0	$0.74^{+0.22}_{-0.34}$	200
W helicity F_+	$F_+ < 0.27 @ 95\% \text{ CL}$	200
Search for anomalous kinematics	Consistent with SM	193
Search for H^+ in t decays	$\text{BR}(t \rightarrow Hb) < 0.91 @ 95\% \text{ CL}$	193
$\sigma_{dilepton}/\sigma_{l+jets}$	$1.45^{+0.83}_{-0.55} \text{ (stat + syst)}$	126
$\text{BR}(t \rightarrow Wb)/\text{BR}(t \rightarrow Wq)$	$> 0.61 @ 95\% \text{ CL}$	162
$\text{BR}(t \rightarrow \tau\nu_\tau q)/\text{BR}_{SM}(t \rightarrow \tau\nu_\tau q)$	$< 5.2 @ 95\% \text{ CL}$	193
Search for 4 th generation t' quark	$m_{t'} < 196, m_{t'} > 207 @ 95\% \text{ CL}$	347
Top quark lifetime	$c\tau_{top} < 52.5 \mu m @ 95\% \text{ CL}$	350

Search for 4th generation t' quark



Search for anomalous kinematics

